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Productivity and Price: The Case of Gold Mining in Ontario

ALAN G. GREEN

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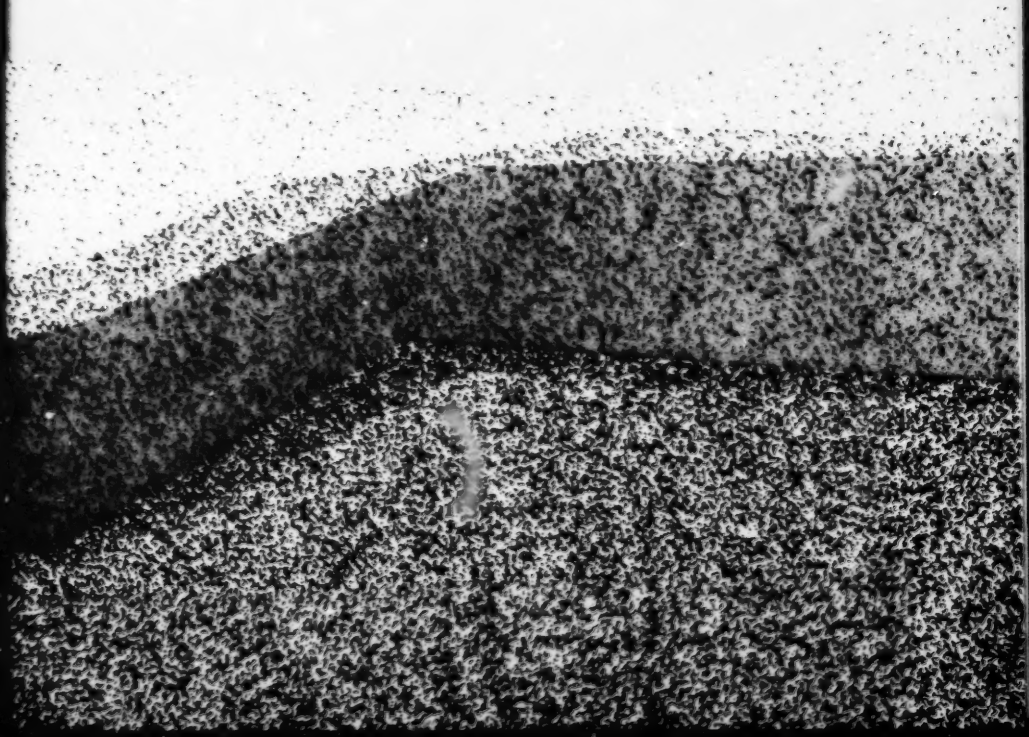

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FOREWORD

This paper represents research sponsored by the Centre for Resource Studies aimed at improving knowledge of the Canadian mineral industry and the political environment in which it operates. The subject of productivity is of vital interest to the industry at the present time, and this study looks at the relationship between productivity and prices for gold, over a period which saw, first, a price fixed by government, and later, a rising free market price.

The Centre's working papers are offered for information and discussion, in an attempt to encourage feedback to the authors and additional research in mineral policy. Opinions presented are those of the author, and do not necessarily represent the views of the Centre or its sponsors.

Margot J. Wojciechowski
Centre for Resource Studies

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SUMMARY

In the mid-1930s, the price of gold was fixed at $35 (U.S.) per ounce. It stayed at that level until 1968, when the price was freed to follow market pressures. By the late 1970s, the price had soared to more than 10 times the old price. It appears that these price changes have had a significant impact on productivity trends in gold mining in Ontario. Before 1968, with rising costs and a fixed price, the industry shrank, reduced investment, and concentrated its remaining resources on the extraction of gold. With rising prices, however, mines began to look to the future and directed their resources away from direct production and into development activities. Empirical evidence indicates that the result was a sharp reversal, beginning in 1973, of the improving productivity trend of the earlier period.

RESUME

Vers le milieu des années 30, l'or avait un prix fixe de 35$ américains l'once. Ce prix est reste inchangé jusqu'en 1968, date á laquelle il est devenu libre pour suivre les pressions du marché. A la fin des années 70, le prix était monté en flèche jusqu'à 10 fois l'ancien prix. Il semble que ces changements de prix aient en un effet considérable sur les tendances de la production dans l'industrie minière de l'or en Ontario. Avant 1968, alors que les coûts allaient croissant et que le prix était fixe, l'industrie devenait moins importante, réduisait l'investissement et plaçait le reste de ses ressources dans l'extraction de l'or. Mais avec la hausse des prix, les mines reprirent de l'essor et commencèrent à consacrer leurs ressources à la mise en valeur plutôt qu'à la production directe. On peut déterminer de façon empirique qu'il en est résulté à partir de 1973 un renversement de la tendance de la productivité qui s'est nettement améliorée par rapport à la période précédente.

1. INTRODUCTION

During the last decade a profound change has taken place in the competitive position of North America vis-a-vis this continent's main trading partners. Productivity in Canada and United States has apparently slipped behind that of Europe, mainly Germany, and Japan. Such comparisons are generally confined to the manufacturing sector: i.e. automobiles, steel, electronics, etc. However, the resource sector is not immune. Maintenance of a strong competitive position for Canada's mineral industry depends not only on the existence of economically viable deposits but in the efficiency with which they are exploited.

This paper deals with one particular case: gold as it is mined in Ontario. Furthermore, it is concerned solely with lode gold mine production. No sizeable amount of placer gold mining was carried on in Ontario and we are not concerned with gold as a by-product of base metal mines. The period covered is from the mid-1960s to the present. These years embrace two different price regimes. For the years 1934-68, gold's price was set at $35 per ounce U.S. and producers were required to sell it at this price, except for small amounts used in various production processes. Beginning in March 1968 a two-tiered price system was established. Central governments stood ready to buy gold at $35 an ounce; however, a free market in gold was also created. Producers then could seek the best price for their commodity.

This paper is divided into three sections. Chapter 2 surveys the market for gold and its price performance over the recent past. Chapter 3 looks at productivity performance in the industry, and seeks explanations for the observed trends in productivity. The last chapter sets out some conclusions about factors which have influenced productivity in this industry.

2. PRICE AND PRODUCTION: THE MARKET FOR GOLD

Demand for gold comes from two sources: industrial and monetary. Industrial demand is the smaller of the two and covers the range of gold used for everything from insulating windows on jets to jewellry and fillings for teeth. Monetary demand is by far the larger of the two, and sets the price of the commodity. Gold throughout the ages has served both as a universal medium of exchange and as a store of value (hoarding). Indeed, until well into the 20th century most countries operated on a gold standard: i.e., local currency supplies were related to the size of gold stocks. Under a gold standard regime, countries were obliged to buy and sell gold at a fixed price, without restraint. This did not eliminate fluctuations in the price of gold but did, largely through the operations of the Bank of England, mean that its price varied over a very narrow range. When economic power shifted to the United States, this meant the price of gold was set in Washington rather than in London.

This shift in economic power from London to Washington made little impact on the price of gold, except that its price was now denominated in U.S. dollars instead of pounds sterling. For almost a century the price of gold remained at $20.67 an ounce (U.S.). This long period of stability changed abruptly in the mid-thirties (1933-34) when President Roosevelt officially raised the price to $35 an ounce. The reason for the increase was the Great Depression of the 1930s: the belief at the time was that, since the price of other commodities was linked to the price of gold, an increase in gold's price would raise the price of other goods and therefore provide a stimulus to the U.S. economy. Unfortunately the shift in the price of gold did little to ease the depressed conditions of the times, either in the United States or in the rest of the world.

The price of gold remained fixed at $35 an ounce for 34 years, and Canadian producers were required, under the terms of Canada's 1932 Gold Export Act, to sell all their gold to the Canadian government at this price. In 1968 a two-tier price regime was introduced: the $35 price henceforth was to apply only to official monetary transactions, and the central banks continued to stand ready to buy all gold offered them at $35 an ounce; the balance of gold exchange was to be determined in the free market. The reason for this shift was the acute balance of payments problem experienced by the United States at the end of the 1960s. In the preceding year the United States had run a

large current account deficit, and hence non-U.S. countries were in possession of large quantities of U.S. currency. As the deficit in the balance of payments deepened, the foreign holders of U.S. dollars believed that the U.S. currency would have to be devalued and so began converting their dollar holdings into gold. This massive conversion served to deplete U.S. stocks of gold, and so, to stem this outflow, the two-tiered system was adopted. By 1971 most of the newly minted gold was going to the open market, since the free market price had risen above $35. Furthermore, central banks refused to sell gold at this price, and the USA renounced its obligation to sell gold. After a brief period of price stability following the adoption of the two-tiered price system, the price of gold soared (see table 1).

Table 1

THE PRICE OF GOLD IN CANADA AND IN THE UNITED STATES
(Dollars per ounce)

Year	Canada (1)	USA (2)	Year	Canada (3)	USA (4)
1960	33.94	35.00	1970	37.55	35.97
1961	35.46	35.00	1971	41.20	40.80
1962	37.41	35.00	1972	57.54	58.13
1963	37.75	35.00	1973	96.38	97.22
1964	37.75	35.00	1974	155.76	159.26
1965	37.73	35.00	1975	163.78	161.02
1966	37.71	35.00	1976	123.11	124.84
1967	37.76	35.00	1977	157.09	147.72
1968	42.83	39.85	1978	220.41	193.23
1969	44.25	41.09	1979	359.29	306.69

Source: Canadian Minerals Yearbook, 1972, 1973, 1976, 1980.

Note: the official price of gold is stated in terms of U.S. dollars. Thus the Canadian price is simply the U.S. price adjusted by the Canadian exchange rate. It is assumed throughout the study that it is the price of gold in Canadian dollar terms upon which producers in Canada make production decisions. Two factors, then, determine price expectations for Canadian producers: the U.S. price per ounce (administered or market determined), and the Canadian exchange rate.

Implications of the Price Change

For our study the recent price history of gold has important implications for efficiency in the industry. Although governments could fix the price of gold, they could not control the cost of mining gold. As long as the producing economies were in a depressed state, or under fixed price and wage constraints as they were during World War II, the price/cost ratio continued at profitable levels. However, following the end of hostilities, and as wages and other prices began to rise, the profitability of gold mining began to decline, especially in the early 1950s.[1]

The decline in profitability was followed by mine closures and cutbacks in production, especially in the years immediately following the end of World War II. The extent of this reduction was so severe that in 1954 it prompted the Ontario government to appoint a Committee of Inquiry, under the Chairmanship of F.A. Knox of Queen's University. The committee issued its report in the form of a monograph entitled Gold Mining in Ontario.[2]

The main conclusion of this study was that by 1955 the gold industry in Ontario was near collapse.[3] Increasing costs and the failure of productivity to offset these increases, along with the fixed price of gold, were seen as the main causes of this situation. The committee offered no solutions, except to recommend an upgrading in the level of education and health services in the mining communities. The purpose of the education recommendation was to encourage out-migration of young people. The only real solution was for the USA to either raise the official price of gold or free it for sale at market-determined prices, with the hope that hoarding demand would exceed increases in world supplies by enough to raise the price of gold to pro-

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1. Note that although prices were fixed and production costs were rising, this does not necessarily mean that profitability had to fall. If efficiency increases had kept pace with rising nominal costs, profitability would have remained unaltered. The fact that profitability was falling indicates that increased productivity, regardless of source, was not sufficient to offset this price/cost squeeze.
2. F.A. Knox, Gold Mining in Ontario, Report of the Committee of Inquiry into the Economics of the Gold Mining Industry, (Toronto: Government of Ontario, 1955).
3. Ibid., p. 60.

fitable levels. Neither of these solutions was under the control of the Ontario government. Relief, as stated earlier, did not come until 1968, and the price of gold remained near the $40 mark until the early 1970s.

The outcome of this continued price/cost squeeze was inevitable: gold production fell. In 1958 production from gold quartz mining in Ontario was 2.7 million troy ounces; by 1978 it had dropped to 700,000 troy ounces.[4] Investment declined; development work was either suspended or carried on at a level below that necessary to insure a healthy and viable industry, and the wages of gold miners were kept below those for other metal mining operations.[5] Thus by the mid 1960s the industry was at the end of a two-decade period of price/cost squeeze. The contention of this paper is that the price, first fixed and then rising steeply, profoundly influenced the development of this industry, especially its longer-term efficiency trend. Price is taken as the exogenous variable.

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4. Ontario Ministry of Natural Resources (OMNR), Metal Mining Statistics, Mineral Policy Background Paper No. 16, Toronto, 1983, p. 23.
5. For selected years the average hourly wages in gold mining as a percentage of average hourly wages in total metal mining was: 1961, .75; 1965, .78; 1970, .72; 1975, .88; 1977, .86. The figures indicate that there was a slight catching up of gold mining wages over the period.

3. PRODUCTIVITY TRENDS

Efficiency changes can be measured by an index of total factor productivity (hereafter TFPI). The following equation was used for gold mining:

$$A_2/A_1 = \left[\frac{Q_2/L_2}{Q_1/L_1}\right]^{S_L} \left[\frac{Q_2/K_2}{Q_1/K_1}\right]^{S_K} \left[\frac{Q_2/E_2}{Q_1/E_1}\right]^{S_E} \left[\frac{Q_2/M_2}{Q_1/M_1}\right]^{S_M}$$

A_2/A_1 measures relative efficiency. The subscripts 1 and 2 denote the two years over which efficiency is being compared. L denotes labour; K is the real capital stock employed; E is the energy used in production, measured in BTUs; and M measures the real value of materials and process supplies (dynamite, wood and steel for shoring shafts, etc.) The respective share costs of the inputs are S_L, S_K, S_E and S_M. Finally, Q represents output, measured in terms of ounces of gold produced. Measuring output by the final product (gold) means that the influence of changing ore grades on efficiency is automatically included in the TFP index.

In this type of analysis two influences are measured. First, changes in partial productivity indices, i.e. Q/L, Q/K, etc. are determined. These are the directly observable influences on productivity. Second, an unexplained residual (A_2/A_1) is estimated. The latter measures the difference between the growth in inputs (labour, capital, materials and energy) and the growth in real output.

There are a number of factors which can explain the growth, or decline, in TFPI. First, technological change will increase the TFPI index by increasing the efficiency of output per unit of input. For example, a new method of extracting ore which uses less labour or less of all the inputs would have this effect. Second, economies of scale influence the relationship between inputs and outputs. A large mining operation may move the firm to a lower point on its long-run average cost curve. This is especially the case where substantial indivisibilities exist in the production process; e.g., where there is a need for large process equipment. Third, an improvement in human capital will increase economic efficiency. A skilled and experienced workforce can obviously improve the quantity of output per unit of input. Finally, organization can affect efficiency. A change in the organization of the industry, say greater integration of existing individual production processes, may improve productivity. The job here, then, is to examine the trends in the TFPI and, in the next section, suggest some explanations for these observed changes.

Table 2 presents the productivity estimates for gold mining in Ontario over the period 1966-77. As the table shows, total factor productivity (col. 5) declined during this period by approximately 9 percent. However, the overall trend by itself is deceiving. Between 1966 and 1972, total factor productivity actually increased by 17 percent. It then fell steeply between 1972 and 1973 and declined slowly from then until 1977. These trend patterns were primarily due to changes in the productivity of materials (col. 4). Up to 1972 the increase in material productivity was reinforced by a growth in labour productivity (col. 1) but countered by a drop in capital productivity (col. 2). After 1972 productivity in materials fell sharply, as did productivity in labour and capital. Given the large weight

Table 2

TOTAL AND PARTIAL PRODUCTIVITY GROWTH IN ONTARIO GOLD MINING

Year	Q/L (1)	Q/K (2)	Q/E (3)	Q/M (4)	A_1 (5)
1966	.1192	.0357	.1133	.2150	1.000
1967	.1270	.0324	.1109	.2439	1.061
1968	.1366	.0305	.1152	.2574	1.109
1969	.1347	.0291	.1043	.2480	1.072
1970	.1462	.0289	.1071	.2634	1.054
1971	.1590	.0295	.1114	.2453	1.156
1972	.1607	.0276	.1142	.2670	1.172
1973	.1499	.0273	.0979	.1861	.995
1974	.1286	.0259	.0885	.1652	.883
1975	.1189	.0240	.0830	.1465	.808
1976	.1427	.0242	.0923	.1673	.895
1977	.1516	.0239	.0917	.1617	.912

Source: See appendices I, II, III and IV for input measure. The method of calculating total factor productivity is set out in appendix VI.

Q = troy ounces of gold produced
L = manhours of labour
K = real capital stock
E = energy measured in BTUs
M = materials input
A = index of total factor productivity
S_L = .5222; S_K = .0749; S_E = .0614; and S_M = .3415

that materials input plays (S_M = .34), efficiency in the use of this input explains a large amount of the observed trend changes in total factor productivity.

Another finding is the unchanged trend in energy productivity (col. 3) from 1966 to 1972, and then its drop for the balance of the period. It would appear that whatever is causing total factor productivity to fall is partially connected with the use of energy. However, energy input is only a small share (S_E = .0614) of total cost; hence it is not a critical factor in determining overall efficiency trends.

Production Costs

Analogous to a production function is a cost function. Table 3 sets out these cost for the various inputs all in current dollars. The estimates shown reinforce the discussion on total factor productivity. Prior to 1972 the total wage bill fell quite dramatically from $31.0 to $20.6 million dollars. This drop paralleled the reduction in production. The materials bill fell as well, from $20.3 to $12.1 million, as did the total cost of energy. In contrast, the service cost of capital actually rose. During the period of declining total factor productivity (i.e. 1972-77), all costs rose, but none so dramatically as that for materials, which more

Table 3

COSTS OF PRODUCING GOLD IN ONTARIO, 1966-77
(millions of current dollars)

Year	Capital	Labour	Energy	Materials	Total
1966	2.232	31.008	3.646	20.280	57.166
1967	2.541	27.802	3.343	16.487	50.173
1968	2.757	25.383	3.011	14.915	46.066
1969	2.792	23.830	3.128	14.318	44.068
1970	2.894	22.264	3.087	11.980	40.225
1971	2.726	20.762	3.005	13.884	40.377
1972	2.804	20.594	2.770	12.016	38.274
1973	2.772	22.818	3.110	18.063	46.763
1974	3.090	28.146	3.509	21.516	56.261
1975	3.674	35.206	4.077	25.136	68.093
1976	3.917	32.904	4.136	33.215	74.172
1977	4.048	32.994	4.979	26.515	64.488

Source: see table 2.

than doubled. Finally, the wage bill rose by one-third, despite a 50-percent drop in manhours worked. Of all the cost increases, then, apparently the one that could be least offset by compensating efficiency gains was material costs. In fact, by 1977, materials' share in total cost almost equalled that of labour cost, whereas in 1966 it was only two-thirds of the wage bill.

The counterpart cost data to the partial productivity indices shown in table 2 are unit cost ratios. These data are presented in table 4 by category (labour, capital, etc.). In addition, a weighted total unit cost index is shown. The latter was derived similarly to the total factor productivity index: i.e. the unit cost figures were weighted by their respective shares (i.e., S_K = .039, S_L = .542, S_E = .064, and S_M = .355) and the results totalled and indexed to the base 1966 = 1.000. The results show that total weighted unit costs for the period of relative price stability, 1966-71, declined by approximately 5 percent, while for the years after 1972, when gold prices increased rapidly, unit costs increased by 15 percent. As in the

Table 4

INPUT COSTS PER TROY OUNCE OF GOLD PRODUCED, ONTARIO, 1966-77

Year	Capital	Labour	Energy	Materials	Total Weighted[a] Unit Costs
1966	1.34	18.67	2.20	12.21	1.000
1967	1.70	18.60	2.24	11.03	.967
1968	2.00	18.39	2.18	10.81	.949
1969	2.27	19.37	2.54	11.64	.996
1970	2.49	19.16	2.66	11.17	.972
1971	2.40	18.31	2.65	12.24	.954
1972	2.75	20.21	2.72	11.88	1.025
1973	3.01	24.75	3.37	19.59	1.368
1974	3.86	35.14	4.38	26.86	1.932
1975	4.87	46.63	5.40	33.29	2.524
1976	5.30	44.53	5.60	44.95	2.765
1977	5.47	44.59	6.73	35.83	2.466

Source: see table 2.

[a] Total weighted unit costs are the sum of the individual factor unit costs weighted by their respective factor shares.

case of total factor productivity, the main elements in this increase were labour and materials.

What appears to have happened, recalling that we are dealing with industry-wide averages, is that, with the elimination of a number of marginal mines in 1966,[6] unit costs declined and remained relatively stable for the period when prices hovered around $35 to $40 an ounce. During the period 1972-77, when gold prices increased from $57 to $157 (Canadian), unit costs accelerated. The central driving force behind this increase was a tripling of material costs. As a result of this rapid increase, material costs, as a share of total costs, were equal to or slightly above those for labour (see table 3), a quite dramatic redistribution of the industry's cost structure.

Prices, Costs and Output: An Analytical Approach

Figure 1 brings together the various empirical elements discussed in the previous section.

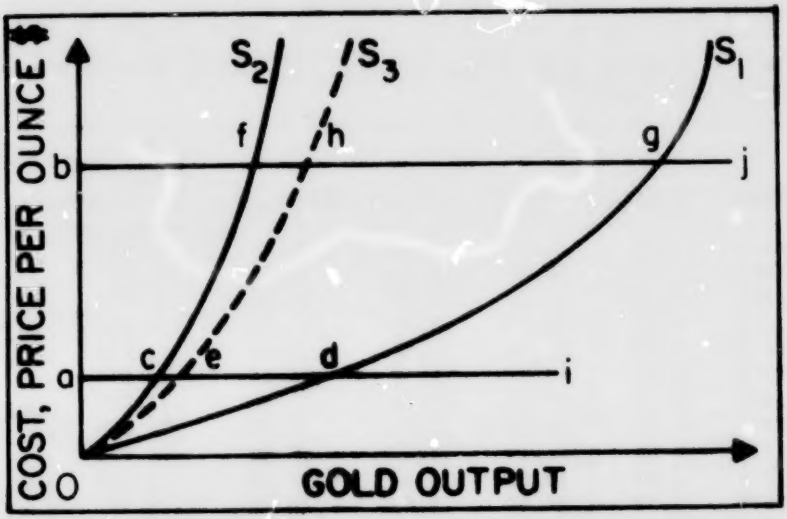

Figure 1. Decreasing Ore Grade

6. Energy, Mines and Resources Canada, Canadian Minerals Yearbook, 1966, states that the large number of mine closures in 1966 was due to 'the exhaustion of

The S curves represent the supply functions for the gold industry. They are shown as nonlinear, since it is assumed that the marginal cost of production rises more steeply per unit of gold produced as the industry draws on ore of ever lower grade. The demand curves for gold (a, i and b, j) indicate that the Ontario gold industry is in the position of a price taker, and as such adjusts output levels to the international price of gold, consistent with profit maximization goals.

The leftward shift of the supply curve (S_1 to S_2) represents an increase in unit costs of production due to the rising prices producers must pay for labour, capital, energy, etc. With the price of gold at Oa, (say the official price, $35/oz. U.S.), the effect of these cost increases is to decrease output from ad to ac. The assumption is that p = mc, where p = price per ounce of gold and mc = marginal cost. With prices fixed, as they were until 1968, it is possible that, in time, the gold industry (once one of the main metal industries in Ontario), would have gone out of business, creating additional unemployment. Even with a price rise to Ob (say due to the beginning of free market price determination), output, due to these steeply rising cost increases, may have declined; i.e., bf < ad, as drawn.

The Canadian government recognized this problem, and in 1948 introduced the Emergency Gold Mining Assistance Act, to assist Canadian gold mine operators in meeting the greatly increased costs of gold production for which, unlike all other primary mine products, there had been no compensating increase in price.[7] The act was still in existence at

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economic ore brought about by ever-increasing costs for supplies and higher wage scales'. Of the five mines which ceased operations in 1966, two, Pickle Crow and Little Long Lac, asked for the maximum assistance under the EGMA that year. Two other mines which folded in 1966, Porcupine Paymaster and Sapawe Mines, had been receiving maximum assistance in the years immediately preceding 1966. (See p. 173 of the Canadian Minerals Yearbook, 1966.)

7. 'The number of assistance ounces is two-thirds of the total ounces produced and sold to the Royal Canadian Mint by a mine in a calendar year. The rate of assistance factor is two-thirds of the amount by which the average cost of production exceeds $26.50. The rate of assistance factor is limited to a maximum of $12.33 which is reached when the average cost of production rises to $45 per ounce of gold produced.' See Report on the Administration of the Gold Mining Assistance Act, Ottawa, 1967, p. 7.

the start of the period under study and, although no money was paid out under the act after 1972 (since no gold was sold to the Royal Canadian Mint during this or subsequent years), the act nevertheless was not abandoned until 1976, in order to provide stability for the industry during this period of large price changes.

As shown in figure 1, the effect of the act was to shift the supply curve to the right, i.e. to S_3, although not in a parallel fashion to supply curve S_2. The reason for the rotation is that the Canadian government set a limit of $12.33 per ounce for assistance. This meant that the production cost per ounce could not exceed $45 (45 - 12 = 33). The level of assistance was calculated on a formula basis (see footnote 7). Thus for low-cost producers the level of subsidy would drop to zero. This is shown in figure 1 where S_3 curve intersects with the S_2 curve.

The exact cut-off point in terms of production levels is not known. In figure 1 the implication is that, as a result of the EGMA, output increased by CE; in other words, total output was ae. If the mines kept operating, and/or maintained the level of production per mine, those in the ce range were clearly extra-marginal in terms of actual (market) costs and prices. It is not hard to envisage a condition where, due to a drop in ore grade mined or a rise in the cost of purchased inputs, a mine could, even with the act, go out of business. The central part of our explanation of total factor productivity, then, must deal with the effects of a prolonged price/cost squeeze (supported by the EGMA), followed by a sudden rise in the world price of gold.

4. EXPLANATIONS OF PRODUCTIVITY TRENDS

The efficiency (A_1) set out in table 2 is often called a 'measure of our ignorance'. This is appropriate since it captures all the unexplained increases in output that are not 'explained' by the growth of measured factor inputs - labour, capital, energy, etc. It is a residual and hence difficult to partition into its sub-components. However, we do know what items are included in this residual: technological change, organizational structure, improvements in the quality of the workforce, and economies of scale. In our case, some combination on all of these various components served to increase productivity by about 17 percent between 1966 and 1972. Thereafter, the growth in measured inputs was greater than any (or all) of these factors and hence measured efficiency declined.

Organization of Production

The organization of production can exert important influences on efficiency. A small scattered production process often means greater costs per unit than is the case when integration of a series of processes at one site or into one system is undertaken. The economics of large scale production that emerge from such a reorganization show up in increased efficiency.

Between 1966 and 1980 the Ontario gold quartz industry underwent a major change in its organization. In 1966 there were 26 producers operating in Ontario. The average quantity of ore hoisted (milled) per mine was 231,000 tons. By 1980 the number of producing mines had dropped to 6 and average production had subsequently increased to 543,000 tons. This change in the average size of production unit occurred during a time (1966-80) when total ore hoisted (milled) declined by about 50 percent, from 6.0 million tons to 3.2 million tons.

Economic theory would predict that the quantity of ore hoisted would decline over time since, as costs (nominal and economic-opportunity costs) rise, the higher price needed to cover these costs would decrease demand. With a perfectly managed resource endowment, the 'choke price' i.e. that price where demand falls to zero, coincides exactly with the exhaustion of the resource. Furthermore, theory suggests that, where orebodies are of different grades, the process of extraction would be from the highest grade to the lowest. This is logically intuitive since mining is simply

an investment activity. Producers then can maximize the present value of their investment expenditure by mining the high grade ore first and poorer grades later.[8] Thus what we would expect to find in a case like Ontario is that the total amount of ore hoisted would decline and the later ores mined would be of lower average grade. In the current case we also observe a change in the organization of production, moving towards fewer and larger producers.

To examine the actual pattern of exploitation for Ontario gold production, table 5 was constructed. This table provides estimates of the weighted and unweighted average ore

Table 5

AVERAGE GRADE OF ORE HOISTED IN ONTARIO GOLD MINES, 1966-80

Year	Unweighted	Weighted	Year	Unweighted	Weighted
1966	.294	.250	1973	.361	.303
1967	.270	.247	1974	.376	.216
1968	.289	.244	1975	.348	.196
1969	.271	.232	1976	.409	.214
1970	.259	.251	1977	.404	.205
1971	.377	.358	1978	.398	.201
1972	.376	.330	1979	.365	.200
			1980	.313	.172

Sources: Ontario Dept. of Mines, Annual Review, 1966-1970. Ontario Mineral Review, 1966-1976 (Annual). Canadian Mines Handbook, 1966-1980 (Annual).

See also appendix VII.

8. The present value (PV) will be greater where operators mine higher grade ores first. Since the price is given, regardless of ore quality, it is impossible for price to equal $(Po - Ca)e^{-rt}$, where Po is the initial price for two different ore grades for $C_b > C_a$, and C_b is the cost of extracting the lower quality ore. For the equality $(P_{tj} - C)e^{-rtj} = (P_{ti} - C)e^{-rt}$ to hold (i.e., the rent must be the same at two different periods of time, with price increasing roughly at the rate of interest r), then the higher grade must be exploited first and be exhausted before work is undertaken on the next lower grade. See O.C. Herfindahl, 'Depletion and Economic Theory', in Economic Theory of Natural Resources, Columbus, Ohio, 1974.

grade hoisted over our period.[9] According to the estimates, on an unweighted basis, average grade of ore hoisted actually rose over the test period, from .294 in 1966 to .313 in 1980. The weighted average tracked the unweighted estimates quite closely until 1974, when the weighted averages began to fall quite rapidly.

Two patterns, then, emerge within our sample set. In the early phase, when prices were relatively stable, small mines hoisting low-grade ore apparently were going out of business: i.e. the weighted and unweighted averages moved more or less in unison. However, in the second phase, when prices rose rapidly, the industry was dominated by larger average-size mines. In addition, these mines were extracting ore of a lower quality. This is revealed in the sharp difference between the weighted and unweighted figures for the period after 1973. By the end of the 1970s, then, the industry structure was dominated by fewer (6 vs. 26) mines, each of which was larger, with these larger mining units extracting ore of a lower average grade.

To get a more direct view of how the structure of the industry changed over the period, a set of frequency distribution diagrams was constructed (figure 2). These frequency diagrams show the number of firms, by class, for four years. The classes measure the amount of ore hoisted in a given year. The pattern of output distribution by size of mine is quite interesting. In 1966 the majority of mines hoisted less than 200,000 tons a year. By 1970, nine of the sixteen mines in operation hoisted less than 400,000 tons a year and within this group the majority were still in the 200,000-tons-and-less category. However, by 1980 no mine hoisted 100,000 tons or less and the majority lifted 200,000 tons or more a year.

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9. The method of estimating weighted average ore grade is as follows:

$$W\bar{G}_t = \sum_{i=1}^{n} \frac{OH_{it}}{\sum_{i=1}^{n} OH_{it}} \cdot \bar{G}_{it}$$

where $W\bar{G}_t$ = weighted average grade of ore hoisted; OH = tons of ore hoisted; G = average grade of ore; i = a given mine; and t = years.

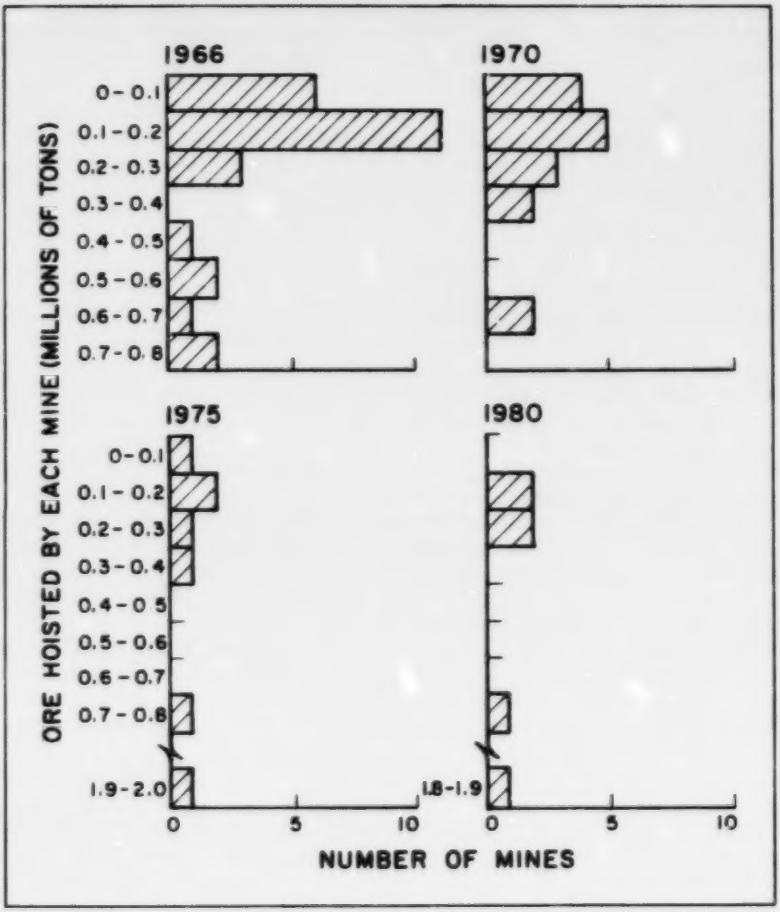

Figure 2. Frequency Distribution of Firms by Tons of Ore Hoisted

This frequency distribution reveals again that, in the early part of the period, the mines leaving were low-grade producers. In the later years the small mines still operating were those hoarding high-grade ore (i.e., the unweighted average was higher in 1980 than in 1966), but the very large scale producers; i.e., those hoisting 600,000 tons or more, were mining very low grade ore. For example, in 1980 Pamour mines which lifted 1.8 million tons of ore had an average grade of .067 while Campbell hoisting only 0.3 million tons had an average grade ten times that of Pamour (.665).[10] These large differences in average ore grade and average size of mine must be taken into account in any interpretation of trends in the efficiency index. The large drop in the efficiency index after 1969 is probably not independent of these changes in the structure of the industry and the lower average grade mined by the large producers. For example, if tons of ore hoisted is substituted for ounces of gold produced, the TFP index actually increases (see appendix I), compared to a decrease when gold output is used (table 2).

On the other hand, some of these negative factors due to reduced average ore grade are partially offset by the economies of scale gained in moving to fewer and larger producers. For example, in the Pamour case, significant economies of scale were achieved in the milling operation by processing the ore output of five mines in two mills. Formerly each mine had its own mill.[11] However, these economies were obviously not sufficient to offset the growth of measured inputs relative to gold output (see tables 2 and 3).

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10. We should not let the geography of the situation escape us. It might be the case that the only way a mine like Campbell Red Lake, situated where it is in northern Ontario, can operate, is if it has access to very high grade ore.
11. In discussing this amalgamation, Cousineau and Richardson say 'Although it is unlikely that any of these mines (belonging to Pamour) would have survived as independent operations, they have been able to achieve significant economies of scale as an integrated group'. E. Cousineau and P.R. Richardson, Gold: The World Industry and Canadian Corporate Strategy, (Kingston: Centre for Resource Studies, 1980) p. 71.

Technological Change

Normally, discussion of trends in the efficiency index concentrates on technological change, since it is often the really important determinant. In the case of gold mining over the last decade or so, however, technological change appears to have played only a minor role in increasing efficiency. Usually the major incentive to introducing new techniques is a rise in labour costs relative to capital costs. In the case of gold mining, real wages did rise rapidly in the 1970s. This sharp increase was due partly to rising gold prices and partly as a reaction to poor wage increases in the industry over the previous decade when gold prices were fixed at $35 per ounce.[12]

Rising labour costs did have some impact. In the late 1970s, mines began to introduce new process methods. For example, larger mines introduced load-haul dump (LHD) equipment and scoop trams. The LHD equipment is capable of transporting up to 6 tons of material from the stope to the ore pass, and replaced more labour-intensive methods.

The milling operations are more difficult to judge. For gold the basic method of liberating the metal from its surrounding rock is termed the cyanidation process, a method developed in 1887. The actual process of recovering the metal has unquestionably improved through time, particularly in that it is now a continuous process. Whether the changes which have occurred over the last decade significantly increased productivity of this segment of the operation is unclear. However, the continuous nature of the recovery method reinforces again the potential economies of scale from ensuring steady flow of feedstock to the mill (recall the discussion on Pamour mines).

Definitive conclusions on the role of technological change in improving efficiency are difficult to make. Innovations were apparently concentrated more in the mining of ore rather than in the recovery stage, although until separate output and input data on milling are available, a definite conclusion is not sensible. What can be said is that capital/labour ratios rose over the period. In 1969 the capital/labour ratio was .70; by 1972 it had risen to 1.19,

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12. Between 1961 and 1970 annual average real wages in gold mining rose by 2.3 percent. However between 1970 and 1977 the annual increase was 18.9 percent. Calculated from OMNR, Ontario Metal Mining Statistics, pp. 66 and 164.

while in 1977 it was 1.35 (see appendix VIII). The exact nature of these capital additions remains to be studied, but they unquestionably exerted a positive effect on labour productivity (see table 2, col. 1).

Human Capital

One obvious way to boost the output per unit of factor input is to improve the training and skill of mine workers. Here the evidence is even more confused. Before the mid-1970s, wages in gold mining averaged about 75 percent[13] of the average wages in other metal mining industries. The reason often given for this discrepancy is that, as profit margins fell, despite the support of the EGMA, a number of mines could survive only by keeping wage increases below those for the industry. Workers accepted these lower increases, so the argument goes, because the local gold mine often was the chief employer in the towns and its closure would throw large numbers of miners out of work (see figure 1 for the effects on employment due to the leftward shift of the supply curve). Furthermore, since many of the mines had been in business for a number of years, the average age of the workers was high and loss of a job could mean permanent unemployment.

The impact of these lower average wages on skill level is mixed. Certainly with wages below market levels for the industry, recruitment of new workers was difficult. However, the older workers must also have been very experienced and thus enhanced overall efficiency. During the later 1970s when wages rose rapidly and development work expanded, it might well have been the case that less experienced workers were drawn into the gold mines, thus lowering productivity. Total labour engaged in gold mining declined over the whole period, so the question of replacement of older workers needs to be studied before any conclusion is possible.

Organisation

The internal organization of the firm must be counted as one of the intangibles influencing efficiency. Cousineau and Richardson[14] have studied this question by examining a

13. Footnote 5 records a selection of these ratios.
14. Cousineau and Richardson, Gold: The World Industry and Canadian Corporate Strategy.

series of specific case histories in the gold mining industry. Their main conclusion is that lack of communication between head office, usually in Toronto, and management at the mine site tends to undermine effective control. Conflict often emerges between mine site management interested in maximizing output - often to insure that mills run close to capacity in order to lower unit costs - and the concern of upper management for meeting nominal profits targets. In such a situation there can be a lack of real concern for productivity: i.e. for questions such as 'What is the marginal return gained by raising an additional tons of ore, vs. the application of labour and capital to new development work?' Apparently the only time such opportunity-cost-related questions are raised is when gold prices are falling.

Cousineau and Richardson find that little fundamental change has taken place in such organizational procedures in recent times, and so little assistance in improving efficiency emerges. If anything, there is the suggestion that, in periods of rapidly rising prices, proper strategic planning procedures are abandoned for the goal of maximizing total revenue, and the goal of maximising long-run productivity growth is neglected.

Measured Inputs

This excursion into the contribution of such efficiency factors as technological change, economies of scale, etc., has produced only limited insights into the sharply different trends in the efficiency index which are observed before and after 1972. Only the possible improvement in the quality of the mining labour force in the earlier period appears to be of any practical importance in explaining some of the 17 percent rise in observed efficiency. The other factors were either small or did not take effect until late in the 1970s. In the latter period the efficiency index of course declined.

Before turning to factors which may have influenced these trends, perhaps it is worthwhile to remove some suggestions that have been offered to explain them. The first is that labour productivity was the main cause of the observed changes: as we saw in table 2, labour productivity increased slightly over the whole period but was greater in 1972 than in 1977; thus mismanagement of the labour factor, i.e. hiring too many workers in boom periods, is obviously

not a cause.[15] The second is that rising energy prices were the main cause of decreased productivity or rising production.[16] Energy productivity did decline slightly (table 2) and energy costs as a share of total costs did rise (table 3), but energy's share in total output is so small (S_E = 0.06) that the input did not account for the large decline in productivity after 1972. What, then, did cause the observed trends?

Examination of the evidence suggests two factors, both price related: a change in the grade of ore; and the allocation of resources between direct gold production and development-related work. In the period prior to 1972, under conditions of extreme price/cost squeeze, survival of many mines, even with EGMA, meant that available resources (men, capital, etc.) had to be applied to direct gold production. Development work (a form of investment where the costs are incurred now and the returns are in the future) was delayed or, with older mines, abandoned altogether.[17] Obviously marginal mines, generally those

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15. In their book on gold, p. 161, Cousineau and Richardson state: 'The decline in productivity from 1972 onwards (at Pamour) can be attributed largely to the failure of the firm to achieve operating efficiencies through ... workforce reductions. However, other factors, such as declining gold grades and decreased individual worker productivity must also have had an influence'. The Pamour experience must have been unique since, although labour productivity for the industry declined a small amount after 1972, it was not the main contributor to the decline in industry productivity.
16. Cousineau and Richardson state, p. 81, 'Milling consumes large quantities of fuel as does air compression, hoisting and underground machinery in the mine itself. Consequently, energy price increases and predicted energy shortages are a major cost concern for the industry'. (The underlining is mine.)
17. 'When the price of gold falls, the first means of cutting costs is often the suspension of development activities. As it does not affect current production, this activity is considered discretionary (much like research and development in manufacturing). However, in reality, the long-term viability of the firm is affected by what are essentially short-run control problems.' Cousineau and Richardson, Gold: The World Industry and Canadian Corporate Strategy, p. 17.

kept alive by the EGMA, probably suspended all such development investment very early and so shortened their useful life.

In addition to this slowdown or stoppage in development work, these marginal mines were forced to raise the cut-off grade mined, and enter what has been referred to as the 'salvage stage' where a substantial share of the labour force works on preparing ore for the mill.[18] We saw in table 5 that the average grade of ore increased sharply during the earlier period. Thus productivity before 1972 increased due to a combination of the two factors cited above: rising average ore grades, plus the allocation of resources towards direct gold production. These two factors offset the worst effects of the price/cost squeeze forced on the industry by a price regime imposed by the international financial community.

These short-run benefits had, however, long-run negative consequences, since development investment is essential if this type of industry is to survive (see footnote 17). The steep rise in prices provided the industry with the necessary opportunity for reinvestment. By 1972 many of the older and smaller mines had closed. In 1968 there were twenty gold mines operating in Ontario but by 1973 only nine mining companies are listed. Furthermore, the larger of these nine mining companies tended to extract lower grade ore. The remaining mines also had large mill capacity which needed a fairly steady flow of feedstock to operate at efficient levels. Maintaining this flow of feedstock required large dollar investment in development work to insure current levels of ore for milling in future years.

The main characteristics of development work are that, besides being fairly labour and capital intensive, the work consumes large quantities of materials: cement, timber, dynamite, etc. If in addition the area being worked underground is unstable, then the quantities of these materials used per foot of new development is even greater. The effect of this increase in material input is shown in tables 2 and 3. The central reasons, then, for the decline in total factor productivity were the shift to lower grade ore, and the associated need for extensive development work which raised measured inputs; indeed, it caused total factor inputs to rise faster than output.

Mismanagement of manpower, increased energy costs, etc., either played no role on the productivity decline or at best were only of minor importance. Decades of low rates

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18. F.A. Knox, Gold Mining in Ontario, p. 33.

of return and the abandonment of major development work induced high grade producers to shift the industry towards a rapid development of low grade ores which, in the short run, sharply reduced industry productivity.

Conclusions

The role of price has proven to be a crucial factor in determining productivity trends in the gold industry, at least for Ontario, over the last two decades. With the price of gold fixed at $35 an ounce U.S., and faced with rising production costs, the industry, even with the EGMA, shrank in size, reduced development investment, and concentrated its resources on extraction of gold. The present dominated the future, a rational response when the future looked so bleak. By the early 1970s hard times had given way to prosperity, as the price of gold was allowed to find its free market level, and as international conditions deteriorated (threat of war, oil shortages, etc.), and the demand for gold soared. With a return to prosperity mines shifted their view to the future, and began large development works which in turn shifted resources away from direct production in the short run and so substantially increased the growth of material inputs. The effect was to reverse the productivity trends of the earlier periods.

These explanations are more in the way of suggestive hypotheses than firm conclusions. However, they are consistent with the empirical evidence. What is needed is a comparative productivity study. For example, what was Quebec's experience in productivity trends over this period and how did large producers like South Africa adjust to such dramatic changes in price trends over the last two decades? This study gives us one point against which these other experiences can be analyzed.

APPENDIX I OUTPUT OF THE GOLD MINING INDUSTRY IN ONTARIO

Year	Ore Hoisted (tonnes)	Gold Produced (troy ounces)
1966	5,906,995	1,660,750
1967	5,410,203	1,495,385
1968	4,863,225	1,379,779
1969	4,606,680	1,229,666
1970	3,851,985	1,161,042
1971	3,769,881	1,133,987
1972	3,400,168	1,019,303
1973	3,349,761	922,303
1974	3,217,878	801,105
1975	3,226,297	755,148
1976	3,006,695	739,547
1977	3,130,359	740,092

Source: OMNR, Metal Mining Statistics, p. 60 and p. 23.

APPENDIX II LABOUR INPUT

Year	Man-hours Paid	Index (1966=1.000)	Cost ($ million, current)
1966	13,933,645	1.000	31.008
1967	11,769,973	.845	27.802
1968	10,101,428	.725	25.383
1969	9,127,331	.655	23.830
1970	7,948,469	.570	22.264
1971	7,133,667	.512	20.762
1972	6,339,578	.455	20.594
1973	6,154,042	.422	22.818
1974	6,228,361	.447	28.146
1975	6,353,042	.456	35.206
1976	5,177,000	.372	32.904
1977	4,875,000	.350	32.994

Source: OMNR, Metal Mining Statistics, p. 66.

APPENDIX III ENERGY INPUT
(measured in BTUs x 10^{11})

Year	Elect. (1)	Natural Gas (2)	Coal & Coke (3)	Gasoline (4)	Fuel Oil (5)	Total (6)	Index (1966=1.000) (7)	Cost ($million, current) (8)
1966	16.69	2.41	1.49	.32	1.59	22.50	1.000	3.646
1967	15.36	2.39	1.41	.27	1.53	20.96	.932	3.343
1968	13.69	2.19	1.16	.19	1.69	18.92	.841	3.011
1969	13.35	1.75	1.03	.24	1.38	17.76	.789	3.128
1970	12.32	1.71	.76	.20	1.54	16.54	.735	3.087
1971	11.18	7.36	.40	.10	1.95	20.99	.933	3.006
1972	9.74	7.42	.07	.10	2.25	19.28	.857	2.770
1973	10.37	7.90	.02	.10	2.25	20.65	.918	3.110
1974	10.19	1.37	.13	.12	1.78	13.58	.604	3.509
1975	10.41	1.53	.02	.10	2.02	14.58	.626	4.077
1976	9.12	1.71	.07	.08	1.32	10.99	.488	4.136
1977	9.19	2.49	.01	.09	1.40	13.18	.586	4.979

Source: OMNR, Metal Mining Statistics, pp. 106 and 107.

Notes: The guantities of the various energy sources were converted to british thermal units (BTUs) by the following factors: Column 1: KwH x 3,410.08 = 1 BTU; Col. 2: cubic feet x 1,200 = 1 BTU; Col. 3: short tons x 200 lbs x 12,000 = 1 BTU; Col. 4: imperial gallons x 1.200949 = U.S. gallons, U.S. gallons x 6.152 = lbs, lbs x 20, 750 = 1 BTU; Col. 5: see Col. 4 but lbs x 19,376 = 1 BTU.

APPENDIX IV MATERIALS AND SUPPLIES[a] INPUT

Year	Real Cost[b] (1935 $ million)	Index (1966=1.000)	Nominal Cost ($ million, current)
1966	7.726	1.000	20.280
1967	6.129	.793	16.487
1968	5.361	.694	14.915
1969	4.959	.642	14.318
1970	4.412	.571	12.980
1971	4.622	.598	13.884
1972	3.817	.494	12.106
1973	4.953	.641	18.063
1974	4.848	.627	21.516
1975	5.155	.667	25.136
1976	4.417	.572	33.215
1977	4.577	.592	26.515

Sources: for cost figures - OMNR, Metal Mining Statistics; for price index - Canadian Statistical Review, Historical Review, 1970; Statistics Canada, p. 66, and The Canada Year Book, 1978/79, p. 886.

[a] Includes such items as explosives, reagents for concentrating ores, steel, lumber, drill bits, repair parts for equipment, etc.

[b] The real cost was derived by using the wholesale price index for non-farm products listed below:

Index (1935-39 = 100)	
1966	262.5
1967	269.0
1968	278.2
1969	288.7
1970	294.2
1971	300.4
1972	317.2
1973	364.6
1974	443.8
1975	487.8
1976	525.6
1977	579.3

APPENDIX V CAPITAL

Nominal and Real Capital Stock

The nominal stock figures were translated into real stock estimates using the Gross Fixed Capital Formulation Price Index listed below.

Year	Nominal Stock ($ million)	Price Index[a] (1971=1.000)	Real Stock[b] ($ million)	Index (1966=1.000)
1966	39.7	.853	46.5	1.000
1967	40.3	.871	46.2	.994
1968	39.7	.877	45.2	.972
1969	38.7	.914	42.3	.910
1970	38.4	.953	40.2	.865
1971	38.4	1.000	38.4	.826
1972	38.8	1.050	36.9	.794
1973	38.6	1.142	33.8	.727
1974	41.2	1.333	30.9	.665
1975	47.2	1.502	31.4	.675
1976	50.2	1.639	30.6	.658
1977	54.7	1.769	30.9	.665

[a] Statistics Canada, National Income and Expenditure Accounts, 1961-1975, 1963-1977.

[b] The real capital stock figures were derived using a perpetual inventory method as described in W.C. Hood and A. Scott, Output, Labour and Capital in the Canadian Economy, pp. 234-237.

Capital Service Price

The formula used to produce the capital service price was arrived with the aid of: D.W. Caves and L.R. Christensen, Productivity in Canadian Railroads, 1956-1975, (for Canadian Transport Commission), 1978; L.R. Christensen and D.W. Jorgenson, 'The Measurement of U.S. Real Capital Input, 1929-1967', The Review of Income and Wealth, Series 15, no. 4, December 1969; and, R.E. Hall and D.W. Jorgenson, 'Tax Policy and Investment Behaviour', American Economic Review, vol. 57, June 1967, pp. 391-414. The capital service price is the cost to a firm of using a real

dollar's worth of capital in a given year. It depends on depreciation and taxation practices, the opportunity cost of capital, the rate of depreciation and the price of new equipment. The formula for the capital service price used in this study is:

$$p = \frac{1 - u_1 z_1 - u_2 z_2 - u_3 z_3}{1 - (u_1 + u_2 + u_3)} \left[r_n \cdot q_{n-1} + \partial \cdot q_n \right]$$

where u_1 = federal income tax rate;
u_2 = provincial mining tax rate;
u_3 = provincial income tax rate;
z_1 = federal depreciation allowance (use the declining balance formula $d \cdot \frac{r+1}{r+d}$, where d is the depreciation rate set in tax laws);
z_2 = provincial mining tax depreciation allowance (use the straight-line formula $\frac{1}{r\ell}\left[1 - \left(\frac{1}{1+r}\right)^{\ell}\right]$, where ℓ is the lifetime allowable for tax purposes).
z_3 = provincial income tax depreciation allowance (use $d \cdot \frac{r+1}{r+d}$. This allowance existed only after 1976 and, thus, before 1976 d = 0, which results in $z_3 = 0$);
r = corporate bond yield rate;
q = index of deflating investment;
∂ = depreciation rate (i.e., $\frac{1}{\text{service life}}$);
n = year.

The federal income tax rate for the part of the period prior to 1974 was taken to be 23.9 percent. That figure can be reached by starting with the federal government's 50 percent basic corporate income tax rate and taking into account:

i the 10-percent discount granted in order to give room for provincial income taxes (this reduced the federal rate to 40 percent).
ii the depletion allowance which reduces taxable income by one-third (thus making the federal rate 26.6 percent).
iii the conditions allowing mines to deduct provincial mining taxes from income in calculating taxable income (in Ontario the mining tax rate is 10.5 percent (see below) and thus the federal rate becomes 23.9 percent).

In 1972 the federal government announced tax changes, but these were not fully implemented until 1974, and thus it is in that year that the new tax rate is used for the first time. Once again, there was a 50-percent basic income tax rate and a 10-percent provincial abatement, but a 15-percent resource abatement was added, reducing the tax rate to 25 percent, and the simple depletion allowance was eliminated. In its place there was a depletion allowance system which granted up to a 25-percent allowance. However since a firm had to invest 43 percent of profits in expansion and exploration to get the maximum allowance, a lesser allowance (15 percent) was assumed here. The result is a federal income tax rate of 21.3 percent.

In 1976 the federal tax rate was changed again. The basic tax rate became 46 percent with a 10-percent provincial abatement, a resource allowance of 25 percent off taxable income, and the same 15 percent off taxable income as a depletion allowance as was used before. From this is derived the 22.9-percent tax rate used for 1976 and 1977.

The provincial mining tax also underwent changes in the period studied here. Before 1964 there was a mining tax of 15 percent on taxable income, which was reduced by a processing allowance for concentration and smelting activities. The allowance could range from 15 percent to 64 percent of taxable income according to the extent of the activities. It has been assumed that an allowance of 33 percent was applicable for the whole industry, in order not to over-emphasize the impact of this allowance and to take into account those mines which had their ore milled at other mine sites. Thus, the provincial tax rate is assumed to be 10.5 percent.

In 1974 the mining tax was changed from the single rate to a graduated rate schedule based on profits. The following list shows the categories and the average tax rate in each:

Profits	Average tax rate
$ 0 - $ 100,000	0.0%
100,000 - 1,000,000	13.5
1,000,000 - 10,000,000	19.4
10,000,000 - 20,000,000	22.1
20,000,000 - 30,000,000	24.7
30,000,000 - 40,000,000	27.3
over $40,000,000	40.0

By working with 'profits as a percent of sales'[1] figures for the gold industry, combined with value of production figures,[2] an unweighted average of profit per firm was worked out. Profits using this method were estimated to be in the $1,000,000-to-$10,000,000 range for 1974 to 1976. Therefore, using a rate of 19.4 percent, and the same processing allowance as earlier (since this part of the system continued as before), a provincial mining tax rate of 13.6 percent was derived. This rate is used in the study from 1974 to 1977.

The provincial income tax was very similar to the federal income tax before 1974. There was a basic rate of 12 percent, a depletion allowance of one-third off taxable income, and a condition allowing provincial mining taxes to be deducted from taxable income. The resultant tax rate was 6.9 percent.

In 1974 the deductibility of mining taxes was disallowed but the rest of the tax setup remained the same. Thus, with a 12-percent basic rate and a one-third depletion allowance, the income tax rate became 8 percent.[3]

Federal depreciation allowances remained the same throughout the period studied here. The federal system allowed different depreciation rates for different types of capital. For the purposes of this study the federal depreciation categories were grouped into three larger categories:

i building construction (mill facility in the federal categorization), with a depreciation rate of 30 percent;
ii engineering construction (infrastructure in federal terms), with a 10-percent depreciation rate;
iii machinery and equipment (mine access, and mine plant and equipment in the federal system), with a 50-percent depreciation rate.[4]

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1. C.H. Pye, Profitability in the Canadian Mineral Industry, (Kingston: Centre for Resource Studies, 1981), p. 63.
2. OMNR, Metal Mining Statistics.
3. The tax information came from: Tax Increases for Mining, 1974, Price, Waterhouse & Co.; Mineral Taxation, 1975, Price, Waterhouse & Co.; 'Now Its Ontario's Turn', Tax Notes for the Mining Industry, Price, Waterhouse & Co.; Federal and Provincial Taxation of the Mining Industry, Coopers and Lybrand, 1980.
4. Depreciation rates from, Effects of Taxation on Base Metal Mining in Canada, by B.W. Mackenzie and M.L. Bilodeau (Kingston: Centre for Resource Studies, 1979).

In order to obtain a single federal depreciation rate, a weighted average of the above three rates was calculated using weights based on the share of each type of expenditure in total expenditure over a 30-year period.[5] The resulting depreciation rate is 23.6 percent. The weights are 11.6 percent for building construction, 60.18 percent for engineering construction and 28.2 percent for machinery and equipment, and are used in the formula $z = d \cdot \frac{r+1}{r+d}$

to calculate the present value of depreciation allowances per dollar invested in capital goods. This formula is used if there is a declining balance method of depreciation. It was obtained from Productivity in Canadian Railroads, 19561975, p. 14.

Provincial depreciation allowances were kept constant up to 1976. The depreciation rate used was 15 percent on a straight line basis. (See footnote 4). The formula for the present value of depreciation allowances when a straight line method is used is $\frac{1}{rl}\left[1 - \left(\frac{1}{1+r}\right)^{l}\right]$, from 'The Measurement of U.S. Real Capital Input, 1929-1967' in The Review of Income and Wealth, 1969, p. 293.

In 1976 the provincial mining tax depreciation allowance, mentioned above, was changed to 30 percent, still on a straight-line basis. In addition, a provincial income tax depreciation allowance of 30 percent on a declining balance basis was instituted. Prior to 1976 this latter allowance was assumed to be 0 percent for the purpose of the capital service price calculation.

The corporation bond yield rate was obtained from Profitability in the Canadian Mineral Industry, by C.H. Pye, p. 38, and the index of deflating investment was found in Statistics Canada, Fixed Capital Flows and Stocks, 1926-1978.

In order to get a capital cost figure, the real capital stock in each year was multiplied by the capital service price for that year.

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5. Information for calculating weights came from Statistics Canada, Fixed Capital Flows and Stocks, 1926-1972, & 1981.

APPENDIX VI TOTAL FACTOR PRODUCTIVITY INDEX

The first step in calculating the total factor productivity index is to calculate the aggregate input index. In order to do this, the four inputs (energy, labour, materials and supplies, and capital) must be individually indexed with 1966 = 1.000. Next, the cost of all the inputs in a given year must be added together to get a total cost figure for that year. Finally, the cost share for each input for a given year must be multiplied by the index value, calculated earlier, for that input and that year, and these products (one for each input) added for that year. The resulting sum is the value in the aggregate input index for the given year; i.e., aggregate input index value for a given year =

$$\sum_{i=1}^{4} c_i \times \sigma_i$$

where c_i = cost share of the i^{th} input and σ_i = the index value of cost for the i^{th} input.

Next, the aggregate output index is calculated. In this case the number of troy ounces of gold produced in each year was indexed with 1966 = 1.000. The final step in calculating the total factor productivity index is to divide the value of the aggregate output index in a given year by the value of the aggregate input index for that year.

APPENDIX VII METHODOLOGY USED TO CALCULATE THE AVERAGE GRADE OF ORE

The average grade of ore is the average number of ounces of gold found in a ton of ore.

i When ore grade was not explicitly stated, the procedure for calculating the average grade is as follows: Data are available on tons milled and number of ounces produced. Therefore by assuming a 93-percent recovery rate (i.e., 93 percent of the gold in the ore is recovered), the following equation permitted an estimate of ore grade:

$$\frac{\text{ounces produced}}{\text{tons milled}} \times .93 = \text{avg. grade.}$$

ii Sometimes ore grade was stated as $dwt/ton. If we let dwt equal dollar worth per ton, the value given can be expressed as a percentage of the prevailing Canadian price per ounce of gold as follows:

$$\frac{\$dwt}{\$price} = \text{grade per ton}$$

iii Having established annual average grades for each mine over the sample period, a weighted annual average for the industry was derived.

$$\text{av. grade}_I = \sum_{i=1}^{t} \left[\sum_{i=1}^{n} \frac{\text{tons}_i}{\text{tons}_I} \times \text{grade}_i \right]$$

where

I = industry
i = individual mine
t = years
n = number of mines

Data sources: Ontario Dept. of Mines, Annual Review 1966-1970; Ontario Mineral Review, 1966-1976; Canadian Mines Handbook, 1966-1980.

APPENDIX VIII TOTAL FACTOR PRODUCTIVITY INDEX USING TONS OF ORE HOISTED AS THE OUTPUT MEASURE

Year	Aggregate Input Index (1966=1.000) (1)	Output (tonnes of ore hoisted) (2)	Output Index (1966=1.000) (3)	TFP Index (3) ÷ (1) (4)
1966	1.000	5,906,995	1.000	1.000
1967	.848	5,410,203	.916	1.080
1968	.749	4,863,225	.823	1.099
1969	.691	4,606,680	.780	1.129
1970	.664	3,851,985	.652	.982
1971	.591	3,769,881	.638	1.080
1972	.523	3,400,168	.576	1.101
1973	.558	3,349,761	.567	1.016
1974	.546	3,217,878	.545	.998
1975	.563	3,226,297	.546	.970
1976	.497	3,006,695	.509	1.024
1977	.489	3,130,359	.530	1.084

Source: for the output statistics, OMNR, Metal Mining Statistics, p. 60; for estimation procedures concerning the aggregate input index, see appendix VII.

APPENDIX IX CAPITAL-LABOUR RATIO

Year	Real Capital Stock (1971 $ million) (K)	Number of Workers (L)	(K/L)x100
1966	46.5	6,634	0.70
1967	46.2	5,767	0.80
1968	45.2	5,014	0.90
1969	42.3	4,526	0.93
1970	40.2	3,969	1.01
1971	38.4	3,510	1.09
1972	36.9	3,111	1.19
1973	33.8	3,133	1.08
1974	30.9	3,067	1.01
1975	31.4	3,187	0.99
1976	30.6	2,624	1.17
1977	30.9	2,288	1.35

Source: for number of workers, OMNR, Metal Mining Statistics, p. 66; for estimation procedures concerning real capital stock, see appendix V.

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